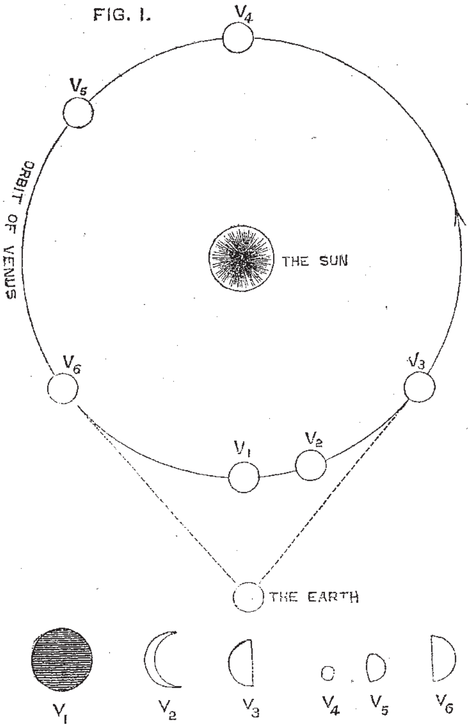
THE COMING TRANSIT OF VENUS

I.

In days of old it was supposed that the earth held the central position of the solar system, and that moon, sun, and planets moved round it, each in its own orbit. The moon was supposed to be nearest to us, then came Venus, then Mercury, after that the sun, then Mars, Jupiter, and Saturn. We now know that of all these the moon is the only one which revolves round the earth, and that all planets go round the sun in the following order :—Mercury, Venus, the earth, Mars, Jupiter, Saturn. These are all the planets which were known to the ancients. Since Mercury and Venus were formerly supposed to be lower than the sun, and all the others higher, the name of *inferior planets* was given to the former, and *superior planets* to the others. These terms are still retained by astronomers, though the ideas that gave rise to these terms are long since exploded. Fig. 1 shows the phenomena exhibited by an inferior planet in the course of its journey round the sun. V is the planet Venus in the different parts of its orbit. E is the earth, which is shown in the figure always in one position, although of course it also describes an orbit round the sun. We are naturally led by a study of the diagram to three points of interest concerning the motions of an inferior planet.

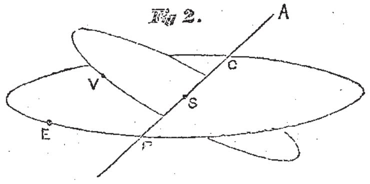
FIG. 1.



The first is that the planet can never seem to be far distant from the sun. Venus moves round the sun in the direction shown by the arrow. The earth rotates in the same direction. We are supposed to be looking down upon the solar system from some point in the northern heavens. It will be noticed that when the planet leaves the point V_1 she will seem to recede from the sun more and more, until she reaches the position V_3. She can never be farther from the sun than this, and is then said to be at her greatest eastern elongation. She then approaches the direction in which the sun is seen, until she is lost in the brightness of his rays. During all this time she is seen best in the early morning before sunrise, setting before the sun. When Venus has passed this position her distance from the sun appears to an observer upon the earth to increase until she reaches V_6, her greatest western elongation, when she again begins to approach the sun.

The next point to be noticed is that she is sometimes a great deal closer to the earth than at other times; and when she is most near to the earth she appears to be larger. At her closest approach to the earth she is only about 26,000,000 of miles away; but when farthest off her distance is 158,000,000 of miles. Her apparent size is therefore much greater in the first case than in the second. These differences are shown at the lower part of Fig. 1.

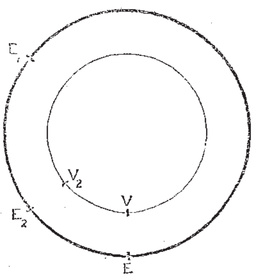
Fig 2.



The third point to be mentioned is that she exhibits phases just as the moon does. In any position that hemisphere alone is illuminated which is directed to the sun; so that in the position V_3, when we can only see one-half of that hemisphere, she will have the appearance of a half-moon. So in the position V_2 she has a crescent form, and at V_5 a gibbous form. The apparent size and shape of the planet in its different positions are shown in the lower part of Fig. 1.

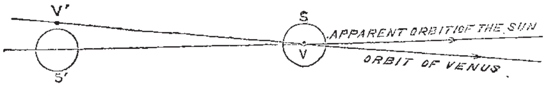
The question now arises, what will happen when Venus is between us and the sun? In the first place, since her illuminated hemisphere is turned away from us, she will appear to be black; so that we shall have no chance of seeing her, unless she be seen as a black spot upon the bright surface of the sun. We would naturally expect that this should happen every time that the planet is at its least distance from us. A simple consideration shows that this need not be the case. The orbits of Venus and the earth do not lie in the same plane. In other words, we cannot represent accurately the paths of Venus and the earth by a drawing upon a sheet of paper. The orbit of Venus would have to be tilted up above the plane of the earth's orbit. Both of these planes pass through the sun, but they are inclined to each other at a certain small angle. This will be seen by a glance at Fig. 2, where V represents the orbit of Venus, E that of the earth. The line AB, which passes through the sun S, is called the line of nodes; and it is quite clear that in order to see Venus as a black spot upon the sun both the earth and Venus must lie approximately on this line of nodes. Now it generally happens that when Venus is at her least distance from the earth, these two planets occupy some such places as V and E, so that she seems to be above the sun; and, not being illuminated, she is invisible. Only twice in a century does she reach the node, so nearly at the same time as the earth, as to be seen as a black spot upon the sun. Such a phenomenon

FIG. 3.



is called a transit of Venus. If it happen that Venus seems to pass across the centre of the sun she takes about eight hours to complete the passage. The earth occupies the position A always in June, and the position B in December. If there be a transit of Venus when the earth is at B, Venus is said to be at the *descending* node, because then she is descending from the northern portion of her orbit to the southern. When Venus is at C she is at her *ascending* node.

FIG. 4

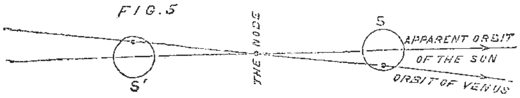


It has been said that there are, roughly speaking, two transits of Venus in a century. The following table shows all the transits of which we know anything :—

1631. Predicted by Kepler, but not observed.
1639. Predicted and observed by Horrox.
1761. Predicted by Halley ; observed by many.
1769. Observed generally.
1874.
1882.

It will be noticed that the transits occur in pairs, eight years apart ; the reason of this can easily be rendered clear. The earth takes 365·256 days to go round the sun ; Venus takes only 224·7 days. Suppose then that at any particular date Venus and the earth are at the node simultaneously, viz. at V and E, Fig. 3, a transit of Venus over the sun's diameter will be seen. When Venus has completed a revolution the earth will have moved away to E_1, and Venus will not overtake the earth until they reach the positions V_2 and E_2. This is 583·920 days from the time when they were at V and E ; but V_2 and E_2 do not lie upon the line of nodes ; hence there can be no transit. After another 584 days Venus will again be in conjunction with the sun, but still not on the line of nodes. But the fifth conjunction occurs after 2919·6 days (5×583·920) ; and the earth completes eight revolutions in 2922·05 days. Thus it appears that, at this conjunction of Venus with the sun, the earth and Venus are very near to their old positions V and E. Hence they are almost on the line of nodes. In this case we can without difficulty examine the possibility of a transit. If we suppose the motion of the earth to be stopped, the apparent motions of the sun and Venus may be represented as in Fig. 4, where a portion of the orbit of Venus and of the ecliptic are shown near the nodes. When the sun and Venus are on the line of nodes simultaneously S represents the sun and V Venus. At the fifth conjunction the sun will not quite have reached S, but will be 2½ days behind at S′ ; Venus will then be at V′. Now in this case there can be no transit visible, for here Venus is quite out of range of the sun. But if in the original transit the sun was a little past the node as at S (Fig. 5), then eight years after he will be at S′, and there will be another transit. It follows from this that there will be a pair of transits eight years apart, only when in the first one Venus does not pass close to the sun's centre. This equality of eight revolutions of the earth, with thirteen of Venus, is very interesting, because this fact was shown by the present Astronomer Royal to account for an inequality in the earth's motion due to the attracting influence of Venus. The result of a short calculation informs us that for positions of Venus and the earth near the line of nodes, Venus is at one conjunction 22′ 16″ distant from her position at the conjunction which occurred eight years previously,* this distance being measured at right angles to the ecliptic. Now the sun's diameter is 32′. This shows why, generally, there are two transits eight years apart.

FIG. 5



The first prediction of a transit of Venus was made by Kepler,† and was calculated from his Rudolphine tables. In 1631, the year predicted, astronomers of Europe were eagerly on the watch for so rare a spectacle. But the calculation was in error, so that it took place when the sun was below the horizon in Europe, and was consequently invisible.

After this no astronomers seem to have interested themselves about the possibility of such an occurrence, with one exception. Jeremiah Horrox, a curate of the village of Hoole, near Liverpool, was much devoted to astronomical pursuits.‡ He possessed some tables for calculating the places of the planets ; but his observations did not agree at all with them. He had, however, before discovering the faults of Lansberg's tables, calculated from them the future positions of the planets. This work, with corrections deduced from his own observations, led him to predict a transit of Venus, visible in England, for the year 1639. He acquainted his friend Crabtree, of Manchester, with the results of his calculation, and then prepared himself for the observation. He considered the best method to be the employment of a telescope to throw an image of the sun on a white sheet of paper in a darkened room. A circle was drawn, of about 6 inches diameter, upon the paper, to make the sun's image exactly fill the circle. A plumb-line would give him the direction of the vertical, and by marking successive positions of the planet on the sun's disc, he would be able to calculate many of the elements of Venus. Such an observation is of course peculiarly well suited for determining the diameter of the planet, the inclination of its orbit, the position of the node, and the true time of passing this node. His calculations showed that the transit ought to commence on the afternoon of November 24 (old style) ; but to guard against disappointment, and because of discrepancies in various tables, he kept a watch from the 23rd. On returning from some clerical duties on the 24th (Sunday) he was gratified by beholding a black spot on the sheet of paper, which indicated the presence of Venus on the sun's disc. He made three observations before sunset and has left us a drawing to illustrate the observations. §

It is curious to find an astronomer supporting the opinions of the astrologers ; but in his treatise we find that the chance of a clouded atmosphere caused him much anxiety, for Jupiter and Mercury were in conjunction with the sun almost at the same time as Venus. This seemed to him to forbode great severity of weather. He adds, "Mercury, whose conjunction with the sun is invariably attended with storm and tempest, was especially to be feared. In this apprehension I coincide with the opinion of the astrologers, because it is confirmed by experience ; but in other respects I cannot help despising their more than puerile vanities." But we must not laugh at Horrox for his opinion. In our own day there is a considerable number of diligent astronomers who believe that the cyclones in the Indian Ocean, certain other winds, the growth of vines, and various other phenomena, are in part regulated by the positions of Venus and Jupiter with respect to the sun.*

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* For at the fifth conjunction the earth is 2·45 days distant from her place at the original conjunction. This is equivalent to 2° 24′ 59″, when viewed from the sun, from which subtract 2′ 44″ (= the retrogression of the node of Venus in eight years), and we have 2° 22′ 15″ = the angular distance of the earth from its corrected original position, as seen from the sun. The ratio of this to the angular distance of Venus from her original position as seen from the earth $= \frac{\text{dist. of Venus from earth}}{\text{dist. of earth from sun}} = \frac{277}{723}$. Multiplying 2° 22′ 15″ by 723, and dividing by 277, we have 6° 11′ 17″. Multiplying this by ·06 = tan 3° 23′ 31″, which is the inclination of the orbit of Venus, we have 22′ 16″ = the latitude of Venus at the fifth conjunction.

† "Admonitiuncula ad Curiosos rerum Cœlestium," Leipsic, 1626.

‡ See NATURE, vol. viii. p. 113,

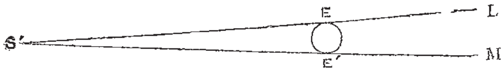
§ Venus in Sole Visa.

Mr. Horrox's observations have been of great value in perfecting the tables of Venus. He was further led by a kind of analogy, much in vogue at the time, to deduce from his observations a value of the sun's distance from the earth. It will readily be understood that if we could find out what size, in angular measure, the earth would seem to have if viewed from the sun, we should have a means of determining how much greater the distance from the earth to the sun is than the diameter of the earth. For, suppose S (Fig. 6) to be the position of an observer placed upon the sun, S L, S M the directions in which he must look to see the opposite sides of the earth, so that the inclination of these lines is known. All we have to do now is to draw a circle of any size and move it about between the lines S L, S M, until it just fills the interval, as at E E′. If now we measure with a ruler how much greater S E is than E E′ we shall know the distance from the earth to the sun, the earth's diameter being taken as the unit of measurement; and if we multiply this by the diameter of the earth measured in miles we shall know the distance from the earth to the sun, in miles. All that we require to know is the size of the angle E S E′. Horrox estimated the probable value of this angle in the following manner. From the observations of Tycho Brahé it appeared that during the transit of Venus the apparent diameter of the planet would be 12′ 18″; while Lansberg found 12′ 21″; and Kepler 6′ 51″. Horrox found from his measurements that it was only 1′ 16″. The error of ordinary observations arises from the apparent enlargement of the planet's disc through irradiation. Gassendi had in the same manner, during the transit of Mercury in 1631, reduced the apparent diameter of Mercury to scarcely 20″. From these data it can be found that the apparent diameters of Venus and Mercury as seen from the sun would be 21″ and 34″ respectively. Proceeding to the other planets he arrived at the general conclusion that each of them would, if viewed from the sun, have an apparent diameter of about 28″. Applying this to the case of the earth, he showed that the distance of the earth from the sun must be 7,500 diameters of the earth (it may be well here to state that the latest measurements show the apparent diameter of the earth as viewed from the sun to be about 18″, and the distance = 11,400 diameters). This analogy by Horrox gave a much closer approach to the truth than any previous conjectures.

Before taking leave of Horrox, we must say a few words to his memory. He died at the early age of 23. During his short career he showed a remarkable aptitude for the acquisition of knowledge, and for the striking out of new ideas. He lived at a time when the scientific spirit of the age was leading up to the theory of gravitation, and many passages in his writings show that he had even then grasped the grand idea of the theory, and that he was well fitted to become its constructor and its expounder. His researches on the lunar and planetary theories indicate the magnitude of his talents.

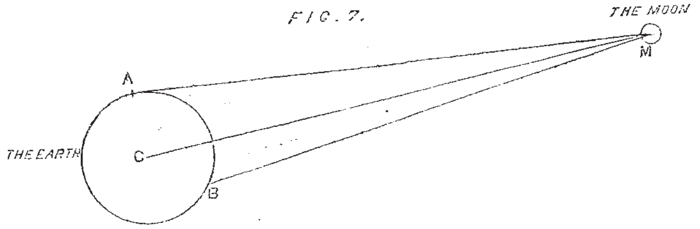
We have already mentioned some of the uses to which careful observations of a transit of Venus may be applied; viz. the correction of the elements of the planet's orbit. But the observation also leads us to a knowledge of the distance of the sun from the earth, and in a manner much more direct and logical than that employed by Horrox. There is an opinion very prevalent that a transit of Venus affords the best means of determining this distance. So far as our present knowledge goes we are hardly justified in such a statement until after the observations that shall be made in the present year.

FIG. 6



Before entering upon the method by which we measure the sun's distance, let us devote a few lines to explaining what is meant by the word *parallax*, which is continually employed in such discussions. Let a man stand in a street exactly north of a lamp-post. The lamp-post will seem to be south of him. Now let him cross over to the other side of the street. The lamp-post will now be in some other direction, such as south-west. This movement of the direction of the lamp-post is the effect of parallax. Now let us suppose, by a stretch of imagination, that a man observes the moon from the centre of the earth. He will see it in the direction C M (Fig. 7). If now he goes to A he will see it in the direction AM. The angle AMC through which the moon appears to have been moved is the parallax of the moon as observed from A.

FIG. 7.



It will be noticed that the parallax is an error introduced into the observed position of the moon, and which must be allowed for if we wish to get the position as seen from C. Moreover, the parallax at B is different from what it is at A. But at no point on the surface of the earth can the parallax be greater than at A. And if we know the parallax of the moon at A, we can deduce that at B from a knowledge of the relative positions of A, B, and C. Hence it is useful to have a distinct name for the parallax at A. Now it will be noticed that a line drawn from C to A is the vertical line at A; hence the moon M will appear to be on the horizon to an observer at A; and hence the moon has its greatest parallax when on the horizon. For this reason the parallax at A is called the moon's *horizontal parallax*. Further, since the equatorial diameter of the earth is greater than the polar, the parallax will be greater, when the moon is on the horizon, to an observer at the equator than to an observer at one of the poles. Hence the greatest parallax we can have occurs when the moon is on the horizon and the observer is at the equator; this value of the parallax is the *equatorial horizontal parallax*. In the same way the sun has an equatorial horizontal parallax, and if we knew its value we could find out the sun's distance from the earth as explained above (Fig. 6).

GEORGE FORBES

(*To be continued.*)

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* See the researches of Messrs. De la Rue, Stewart, and Loewy on the connection of sun-spot frequency with planetary positions, "Phil. Trans."; also the writings of Mr. Meldrum, Mr. E. J. Stone, Prof. Balfour Stewart, M. Poey, and others, on the connection between terrestrial phenomena and sun-spot frequency.